Title: APolarizedDrell-Yan Experiment to Probethe Nucleon Sea

Author(s): Kleinjan, David William

Intended for: American Institute of Physics
Diffraction20124, 2014-09-10 (Primosten, Croatia)
Web

Issued: 2015-03-26

A Polarized Drell-Yan Experiment to Probe the Dynamics of the Nucleon Sea

David Kleinjan

P-25, Los Alamos National Laboratory
Los Alamos, NM 87545 USA
kleinjan@lanl.gov

Abstract. In QCD, nucleon spin comes from the sum of the quark spin, gluon spin, and the quark and gluon orbital angular momentum, but how these different components contribute and the interplay among them is not yet understood. For instance, sea quark orbital contribution remains largely unexplored. Measurements of the Sivers function for the sea quarks will provide a probe of the sea quark orbital contribution. The upcoming E1039 experiment at Fermilab will measure the Sivers asymmetry of the sea quarks via the Drell-Yan process using a 120 GeV unpolarized proton beam directed a transversely polarized ammonia target. We report on the status and plans of the E1039 polarized Drell-Yan experiment.

Keywords: Polarized Drell-Yan Experiment, Sivers asymmetry; Polarized Target
PACS: 13.85.Qk, 13.88.+e, 14.20.Dh, 24.85.+p, 25.40.Ve

INTRODUCTION

One of the current challenges in nuclear physics is determining the origin of the nucleon spin $S_n = 1/2$. The original naïve picture explained the nucleon spin in terms of the spin of the quarks. Results from the polarized Deeply Inelastic Scattering (DIS) EMC experiment at CERN found that only a small fraction of the nucleon spin is carried by the quarks [1, 2]. A more complete description of the nucleon spin is given as

$$S_n = 1/2 = \Delta\Sigma + \Delta G + L_q + L_{q,\bar{q},g} \tag{1}$$

where $\Delta\Sigma$ is the net quark spin from all flavors, ΔG is the net gluon spin, and $L_{q,\bar{q},g}$ is the orbital angular momentum contribution from the respective quarks, anti-quarks, and gluons. The net quark spin has been highly constrained by various experiments to be $\Delta\Sigma \approx 30\%$ [3]. Recent results from RHIC indicate that the gluon spin contribution is nonzero, $\Delta G = 20 \pm 12\%$ [4]. Thus up to 50% of nucleon's spin could be contained within partonic orbital angular momentum.

Analysis of data from polarized Semi-Inclusive Deep Inelastic Scattering (SIDIS) show that there are non-zero orbital angular momentum contributions from the valence u and d quarks which are equal in magnitude, but opposite in sign, $L_q = L_u + L_d \approx 0$ [5]. Recent calculations in lattice QCD predict both these behaviors [6, 7], and predict that a large contribution of the nucleon spin comes from the orbital angular momentum of the sea quarks, $L_{\bar{q}}$.

The spin contribution of the orbital angular momentum of sea quarks remains largely unexplored. Hints of a non-zero orbital angular momentum have already been observed. Using proton induced Drell-Yan, the E866 experiment at Fermilab found an excess of $\bar{d}$ to $\bar{u}$ quarks, as seen in the $\bar{d}(x)/\bar{u}(x)$ ratio in Fig. 1 [8]. Several models explain this $\bar{d}(x)/\bar{u}(x)$ ratio, among them the pion cloud model [9]. The pion cloud model describes the proton as a linear combination of a bare proton plus pion-baryon states.

$$|p\rangle = |p\rangle + |N^0\pi^+\rangle + |\Delta^{++}\pi^-\rangle + \ldots \tag{2}$$

Since the proton is more likely to be in the pion-nucleon state than the pion-delta state, this leads to an excess of $\bar{d}(x)$ versus $\bar{u}(x)$. The proton's positive parity must be conserved. Since the baryon has positive parity and the pion has negative parity, the pion cloud must be in an odd angular momentum state with respect to the baryon, *i.e.* its substituent anti-quark will carry non-zero angular momentum, $L_{\bar{q}}$.

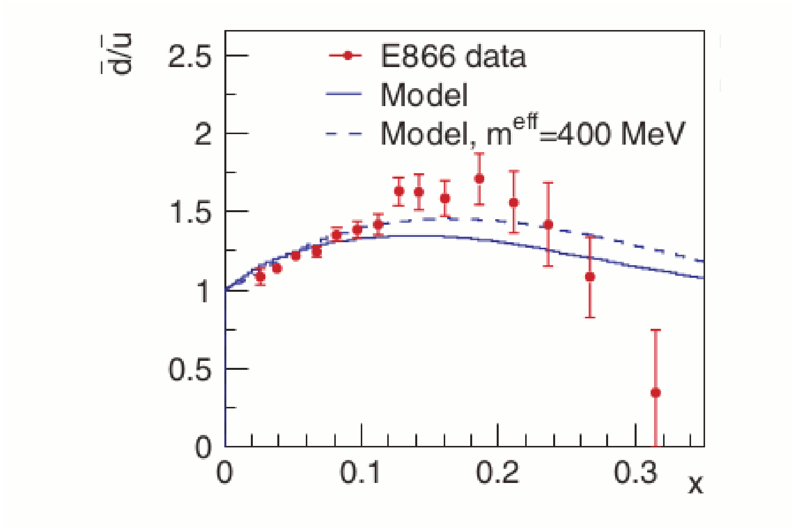

FIGURE 1. The $\bar{d}(x)/\bar{u}(x)$ ratio measured by the E866 collaboration [8], compared to predictions pion cloud model [9].

MEASURING SEA QUARK ANGULAR MOMENTUM

The Sivers function is a transverse momentum dependent (TMD) parton distribution function (PDF) which describes spin-momentum correlations between the transverse spin of the nucleon and the transverse momentum k_T of the parton [10, 11]. It was originally formulated to explain the large transverse single spin asymmetries (SSAs) measured for inclusive hadron production in $p+p^{\uparrow}$ collisions [12]. The Sivers function provides information on the orbital angular momentum contribution of partons to the spin of the nucleon. The quark Sivers distribution can be directly accessed from measured transverse SSAs in Polarized SIDIS $\left(e+p^{\uparrow}\rightarrow e+h+X\right)$ or Polarized Drell-Yan $\left(p+p^{\uparrow}\rightarrow\gamma^{*}\rightarrow\ell^{+}\ell^{-}\right)$. The latter of these has never been carried out experimentally. The same Sivers distribution is involved in both processes. However, transverse SSAs in SIDIS are the result of an attractive final state interaction whilst in Drell-Yan they are the result of a repulsive initial state interaction. This leads to a sign change in the observed Sivers function

$$f_{1T}^{\perp q}|_{SIDIS} = -f_{1T}^{\perp q}|_{DY} \tag{3}$$

Initial transverse SSA measurements in polarized SIDIS have been used to measure the valence quark Sivers function, which as already mentioned have been used to show $L_q = L_u + L_d \approx 0$ [5]. However, due to valence and sea quark mixing in SIDIS, the sea quark Sivers function remains poorly constrained.

The advantage of measuring the transverse SSA from the polarized Drell-Yan process is that the valence-sea quarks can be isolated from each other. In addition, there are no fragmentation functions involved, so the transverse SSA of polarized Drell-Yan, or *Sivers asymmetry*, is directly related to the Sivers function. Thus future measurements of Sivers asymmety are an excellent way to measure the sea quark Sivers distribution, as well as test the sign change between SIDIS and Drell-Yan.

EXPERIMENT

The E1039 experiment [13] will measure the Sivers asymmetry of the Drell-Yan process from an unpolarized proton beam on a polarized target via its decay into muons

$$A_N^{Sivers}\left(p_{beam}+p_{target}^{\uparrow}\rightarrow\gamma*\rightarrow\mu^{+}\mu^{-}\right)\propto\frac{N_L^{DY}-N_R^{DY}}{N_L^{DY}+N_R^{DY}} \tag{4}$$

The dimuon pairs will be measured using the existing muon spectrometer used in the E906 Drell-Yan experiment at Fermilab [14]. That setup currently provides measurement of DY pairs from unpolarized proton collisions with a

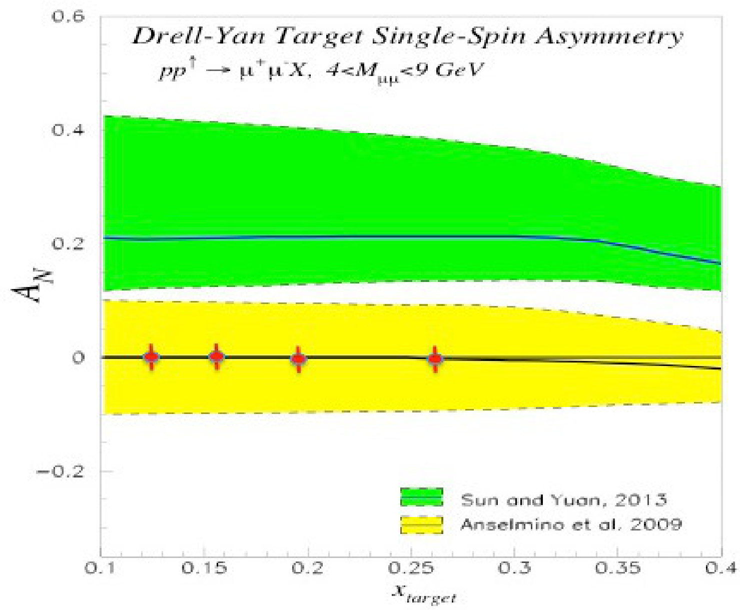

FIGURE 2. The projected error on the measurement of A_N^{Sivers} for two years running based on annual POT $= 2.6 \times 10^{18}$, compared to two predictions [17, 18].

momentum fraction in the target of $0.1 < x_2 < 0.5$, which is also the ideal range to measure the Sivers asymmetry in polarized Drell-Yan. The existing 120 GeV Main Injector beam provided for the E906 experiment is also sufficient for E1039.

The polarized target will be made of irradiated ammonia (NH_3). The irradiation of ammonia makes it paramagnetic, allowing the use of *Dynamic Nuclear Polarization* (DNP) to polarize the protons in the hydrogen atoms of NH_3 [15]. When induced at a low temperature of $T = 1$ Kelvin, and a high magnetic field of $B = 5$ Tesla, polarization of the protons in ammonia can reach up to $P = 92\%$, which is measured using a *Nuclear Magnetic Resonance* (NMR) technique [16]. A liquid helium refrigerator system is used to cool the 5-T superconducting coils which provide the magnetic field to the ammonia target, as well as cool the ammonia target to 1-K using liquid Helium evaporation.

OUTLOOK

The measurement of the Sivers asymmetry by the E1039 experiment will provide a first look into the $\bar{u}$-quark Sivers function.

$$A_N^{Sivers}\left(p_{beam} + p_{target}^{\uparrow} \rightarrow \gamma* \rightarrow \mu^+\mu^-\right) \propto \frac{f_1^u(x) \cdot f_{1T}^{\perp,\bar{u}}(x)}{f_1^u(x) \cdot f_1^{\bar{u}}(x)} \tag{5}$$

Using the projected beam luminosity, and the target, accelerator, and muon spectrometer efficiencies, one year of running at E1039 will provide 2.6×10^{18} Protons on Target (POT). Figure 2 gives the projected error on the Sivers asymmetry measurement for two years of running.

This experiment will provide the first measurement of the sign and magnitude of the sea-quark orbital angular momentum within the proton. If $A_N^{Sivers} \neq 0$, it will be the first experimental evidence to show that $L_{sea} \neq 0$, a crucial piece of the nucleon spin puzzle. Equally interesting is if A_N^{Sivers} is consistent with zero. If $A_N^{Sivers} = 0$, the observed $\bar{d}(x)/\bar{u}(x)$ flavor asymmetry, and the origin of the nucleon spin, will remain a mystery. Regardless of the findings, the measurement of A_N^{Sivers} at E1039 is sure to provide new insights into nature of the nucleon.

REFERENCES

1. J. Ashman, et al., *Phys.Lett.* **B206**, 364 (1988).
2. J. Ashman, et al., *Phys.Lett.* **B328**, 364 (1989).
3. S. D. Bass, *Rev. Mod. Phys.* **77**, 1257–1302 (2005).
4. E. Aschenauer, et al., The rhic spin program, achievements and future opportunities, Tech. rep., Brookhaven National Laboratory (2012), `http://www.bnl.gov/npp/docs/RHIC-Spin-WriteUp-121105.pdf`.
5. M. Anselmino, M. Boglione, and S. Melis, *Phys. Rev. D* **86**, 014028 (2012).
6. K. Liu, et al., Quark and glue momenta and angular momenta in the proton - a lattice calculation (2012), `http://arxiv.org/abs/1203.6388`.
7. M. Deka, et al., A lattice study of quark and glue momenta and angular momenta in the nucleon (2013), `http://arxiv.org/abs/1312.4816`.
8. E. A. Hawker, et al., *Phys. Rev. Lett.* **80**, 3715–3718 (1998).
9. J. Alwall, and G. Ingelman, *Phys. Rev. D* **71**, 094015 (2005).
10. D. Sivers, *Phys. Rev. D* **41**, 83–90 (1990).
11. D. Sivers, *Phys. Rev. D* **43**, 261–263 (1991).
12. D. Adams, et al., *Phys. Lett.* **B264**, 464 (1991).
13. A. Klein, et al., Letter of intent for a drell-yan experiment with a polarized proton target (2013), `http://www.fnal.gov/directorate/program_planning/June2013PACPublic/P-1039_LOI_polarized_DY.pdf`.
14. L. Isenhower, et al., Proposal for drell-yan measurements of nucleon and nuclear structure with the fnal main injector (2006), `https://www.fnal.gov/directorate/program_planning/Proposals/E906-Drell-YanOct2006PAC.pdfProposals/E906-Drell-YanOct2006PAC`.
15. D. Crabb, and W. Meyer, *Ann. Rev. Nucl. Part. Sci.* **47**, 67–109 (1997).
16. C. Keith, et al., *Nucl. Instrum. Meth.* **A501**, 327 – 339 (2003), ISSN 0168-9002.
17. M. Anselmino (2013), private communication. Calculation based on [19].
18. P. Sun, and F. Yuan (2013), private communication. Calculation based on [20].
19. A. M., et al., *Eur. Phys. J.* **A39**, 89–100 (2009).
20. P. Sun, and F. Yuan, *Phys. Rev. D* **88**, 114012 (2013).